The Universe at Low Radio Frequencies
IAU Symposium, Vol. 199, 2002
A. Pramesh Rao, G. Swarup and Gopal-Krishna, eds.

Extended X-ray Emission from FRIIs and RL Quasars

G. Setti, G. Brunetti

Dipartimento di Astronomia, Universitá di Bologna, Istituto di Radioastronomia del CNR, Bologna,Italy

A. Comastri

Osservatorio Astronomico di Bologna,Italy

Abstract.
We review the evidence that detectable fluxes of X-rays are produced by inverse Compton scattering of nuclear photons with the relativistic electrons in the radio lobes of strong FRII radio galaxies within the FRII-RL quasar unification scheme. We report here on the possible detection of this effect in two steep spectrum RL quasars. This may have important implications on the physics and evolution of powerful radio galaxies.

1. Introduction

Synchrotron radio emission from the extended lobes of strong radio galaxies and radio-loud (RL) quasars samples ultra relativistic electrons. It is customary to estimate the average magnetic field via the minimum energy argument using the emitted radio flux in the 10 MHz – 100 GHz band (source rest frame). Since the critical frequency emitted in the synchrotron process is $\nu(MHz) \sim B(\mu G)(\gamma/10^3)^2$ and typically $B(\mu G) > 10$, it then follows that only electrons with Lorentz factor $\gamma > 10^3$ are taken into account. These electrons are also responsible for producing X-rays via the inverse Compton (IC) scattering of the cosmic microwave background (CMB) photons $[\epsilon(keV) \sim (\gamma/10^3)^2]$. When these X-rays are detected, the number of ultra-relativistic electrons is fixed and from the radio flux one can uniquely determine the average magnetic field intensity. Up to now, because of the weakness and diffuse nature of the predicted X-ray emission, detection of X-ray fluxes due to this process has been possible for a few sources only, notably Fornax A (Feigelson et al. 1995; Kaneda et al. 1995) and Cen B (Tashiro et al. 1998); the derived magnetic field intensities are lower than the classical equipartition values by factors 1.5–2.

Brunetti, Setti & Comastri (1997) have pointed out that sizeable X-ray fluxes can also be emitted by the IC scattering of relativistic electrons in the FRII's radio lobes with the IR photons from a quasar, and associated circum-nuclear dusty/molecular torus, hidden in the galaxy's nucleus. Since the IR emission peaks at $50 - 100\mu m$ electrons at lower energies ($\gamma < 500$) are involved in this process. Of course there are no reasons why these lower energy particles shouldn't be present, on the contrary one would expect them on physical grounds based on acceleration and loss mechanisms. In order to estimate the

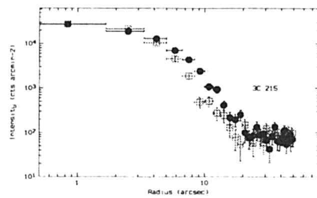

Figure 1. Mean X-ray intensity along (filled dots) and perpendicular (squares) to the radio axis of 3C 215

size of the expected X-ray flux, for a given quasar IR emission, one may work out the equipartition by extrapolating downward the electron spectrum derived from the synchrotron emission to a minimum energy (γ_{min}) limited from below by possible Coulomb losses. The equipartition fields (B_{eq}) so derived are stronger than the classical one by factors from 1.5 to 3 (also Setti, Brunetti & Comastri 1999). We have shown that the IC scattering of the IR nuclear photons may easily account for a large fraction of the extended X-ray emission of several powerful FRIIs at large redshifts ($z \sim 1$) detected by ROSAT in the 0.1–2.4 keV interval.

Morphologically there are two important aspects that should be mentioned: firstly, for obvious geometrical reasons, the X-rays from the IC scattering of the quasar photons are more concentrated toward the nuclear region than those from the IC scattering of the CMB photons and, secondly, given two symmetrical radio lobes the X-ray emission from the far lobe can be much larger than that from the near one, depending on the orientation of the radio axis with respect to the line of sight, due to the enhanced efficiency of head-on scatterings (Brunetti et al.1997). It should also be mentioned that, while the X-rays from the IC scattering of the CMB photons must have a spectral slope coincident with that of the synchrotron radio emission, the X-ray spectrum associated with the IC scattering of the nuclear photons may or may not have the synchrotron slope simply because a different portion of the primary electron spectrum is being sampled (see also Brunetti 2000).

Direct evidence of extended X-ray emission from the IC scattering of the IR photons from a hidden quasar has been gathered by Brunetti et al.(1999) making use of ROSAT HRI observations of the powerful, double lobed radio galaxy 3C 219. The residual X-ray distribution after subtraction of the absorbed, unresolved nuclear source is remarkably coincident with the radio structure. The central extended ($\sim$ 100 kpc) X-ray emission, somewhat stronger in the counter-jet side as expected in our model, can be accounted for by assuming a magnetic field $\sim$ 3 times weaker than our equipartion value ($B_{eq} \simeq 10\mu G$, $\gamma_{min} = 50$). Of course this estimate depends on the assumed IR power of the hidden quasar which we have derived by two, albeit indirect, approaches since 3C 219 has not been detected by IRAS and not observed by ISO. Observations with *Chandra*, scheduled in the fall of the year 2000, will likely provide a check of our model.

2. IC X-rays from the Radio Quasars 3C 215 and 3C 334

Extended X–ray emission around RL quasars has been recently discovered from the analysis of ROSAT HRI observations (Crawford et al. 1999; Hardcastle & Worrall 1999). The origin of the extended and rather weak component (5–15% of total intensity) is usually ascribed to thermal emission from the surrounding intracluster medium (ICM), although a significant contribution from the IC scattering of the quasar's photons predicted by our model cannot be excluded (Crawford et al. 1999).

In order to test the IC hypothesis we have carried out a detailed analysis of the spatial profiles of the sources in the Crawford et al.(1999) sample. The data retrieved from the public archive have been analyzed following a procedure similar to that in Crawford et al.(1999), but the azimuthal distribution has been investigated with the aim of checking for a possible correlation with the radio structure. Accordingly the source counts have been subdivided in four quadrants centered on the quasar (X-ray source peak) and so oriented that two opposite quadrants are aligned with the radio axis defined by the direction of the innermost radio lobes. We have then compared the source counts in the two quadrants along the radio axis with those collected in the perpendicular direction.

We find evidence of X–ray extension spatially correlated with the radio axis in two quasars: 3C 215 and 3C 334. For 3C 48, 3C 254 and 3C 273 our analysis is inconclusive since their radio angular sizes are lower then, or comparable to, the HRI PSF. For 3C 215 (Fig.1) the effect is strong : a KS test rejects at 99.9% level the hypothesis that the count distributions along (filled dots) and perpendicular to (open squares) the radio axis are extracted from the same population. In the case of 3C 334 (not shown here), although the count distribution along the radio axis systematically exceeds that in the perpendicular direction, the effect is statistically marginal (the same KS test gives $\sim 92\%$).

In order to check whether the elongation on ~ 10 arcsec scale could be due to an intrinsic elongation of the HRI PSF and/or to an insufficient correction of the wobbling, we have analyzed several isolated stars (companion at least 6 mag fainter) with similar count statistics extracted from the RASSDWARF catalogue (Huensch et al. 1998): no evidence of asymmetric distributions has been found. Moreover the count profiles of 3C 215 and 334 in the direction perpendicular to the radio axis are consistent with those of spatially unresolved sources.

The X–ray fluxes (0.1–2.4 keV, spectral index $\alpha = 1$) associated with the extended structures have been estimated by subtracting the counts within the quadrants in the direction perpendicular to the radio axis from those within the quadrants aligned with radio axis: the luminosity of 3C 215 is $\sim 1.5 \cdot 10^{45}$ erg s^{-1} of which $\sim 2.2 \cdot 10^{44}$ erg s^{-1} in the extended component, while for 3C 334 one has $\sim 10^{45}$ erg s^{-1} and $\sim 10^{44}$ erg s^{-1}, respectively $[H_o = 75$ km/s/Mpc, $q_o = 0]$.

Knowledge of the quasar IR radiation is of crucial importance for the computation of the expected IC X-ray fluxes. Unfortunately no FIR data are available for 3C 215, while 3C 334 has been observed by IRAS with a $60\mu m$ luminosity of $\sim 10^{46}$erg s^{-1} (van Bemmel et al. 1998). By adopting typical quasar SEDs we estimate a $1 - 100\mu m$ luminosity of $\sim 10^{46}$ erg s^{-1} and $\sim 4 \cdot 10^{46}$ erg s^{-1} for 3C 215 and 3C 334, respectively. Following Brunetti et al.(1997) model we find

https://doi.org/10.1017/S0074180900168986 Published online by Cambridge University Press

that the magnetic field intensities required to fully account for the X-ray fluxes of the extended components are ~ 5 and ~ 3 times smaller than B_{eq} for 3C 215 and 334, respectively. In each source B_{eq} has been calculated by extrapolating downward to $\gamma_{min} = 50$ the power law electron spectrum derived from the low frequency radio spectrum. It should be pointed out that by applying the standard equipartition we would have obtained factors ~ 2.6 (3C 215) and ~ 2 (3C 334) below the corresponding equipartion fields, but this would be conceptually wrong.

3. Conclusions

There is supportive observational evidence of extended X-ray emission from the IC scattering of quasar IR photons with relativistic electrons in the lobes of powerful radio galaxies. Besides being a confirmation of the FRII–quasar unification, this may provide an important tool for the diagnostic of the relativistic plasma at particle energies not sampled by radio observations. The unavoidable presence of lower energy particles implies stronger magnetic fields than derived by standard equipartition formulae and, consequently, a larger pressure inside the lobes. Moreover, accounting for the extended X-ray emission in sources for which the quasar radiation can be constrained indicates magnetic field strengths lower than equipartition. Therefore, confirmation of our IC model by *Chandra* and XMM satellites may provide important clues on the physics and evolution of radio sources.

It is a pleasure to thank C.S. Crawford, A.C. Fabian and I. Lehmann for informative discussions concerning 3C 215 and 3C 334.

References

Brunetti G., 2000, APh 13, 105

Brunetti G., Setti G., Comastri A., 1997, A&A 325, 898

Brunetti G., et al., 1999, A&A 342, 57

Crawford C.S., et al., 1999, MNRAS 308, 1159

Feigelson E.D., et al., 1995, ApJL 449, 149

Hardcastle M.J., Worrall D.M., 1999, MNRAS 309, 969

Huensch M., Schmitt J.H.M.M., Voges W., 1998, A&AS 132, 155

Kaneda H., et al., 1995, ApJL 453, 13

Setti G., Brunetti G., Comastri A., 1999, in 'Diffuse Thermal and Relativistic Plasma in Galaxy Clusters', eds. H.Böhringer, L.Feretti, P.Schuecker, MPE Report 271, p.55

Tashiro M., et al., 1998, ApJ 499, 713

van Bemmel I.M., Barthel P.D., Yun M.S., 1998, A&A 334, 799